Seismic driven reservoir characterization, offshore Niger Delta, Nigeria

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Summary

This paper presents the subsurface characterization by applying integrated three dimensional seismic attributes analysis on a 3D seismic dataset from OPO field, within the western Niger Delta basin. The volume attributes aimed at extracting features associated with hydrocarbon presence detection, net pay evaluation and porosity estimation for optima reservoir characterization. Neural network (NN) derived chimney properties prediction attribute was used to evaluate the integrity of the delineated structural traps. Common contour binning was employed for hydrocarbon prospect evaluation, while the Seismic coloured inversion was also applied for net pay evaluation. Amplitude anomalies were used to delineate bright spots and flat spots; good reservoirs in term of their porosity models, and fluid content and contacts (GOC & OWC) were identified in the area through common contour binning, seismic colour inversion and supervised NN classification.

Introduction

Niger Delta is among the world's hydrocarbon provinces with proven ultimate recoverable reserves approximately 25.8 billion bbl. of oil and vast gas resources. This petroliferous basin is one of the highest producing basins with more promising reserves yet to be discovered as exploration proceeds into the deeper waters. It has therefore become necessary to apply new exploration and production technologies to harness these hydrocarbon resources. Seismic chimney cube, Common Contour Binning (CCB) and Seismic coloured inversion (SCI) are newly introduced approaches to reservoir characterization.

Neural network modelled seismic chimneys are usually associated with chaotic reflections on seismic sections with low energy and low trace-to-trace similarity. Since the first publications on this technology (Meldahl et al., 1999; Hegland et al., 1999), many other successful applications of chimney cubes in revealing vertical hydrocarbon migration pathways, bright spots, salt diapers, sand bodies, channels, fault seal analysis and prospect ranking have been reported around the world (Meldahl et al., 2001; Amizadeh and Connolly, 2002; Connolly et al., 2002; Lightemberg and Thomsem, 2003). Neural network modelled seismic chimneys technology is a powerful exploration tool to delineate trapping mechanisms and hydrocarbon movements between chimneys and faults with a view to reducing exploration risk in reservoirs and seals.

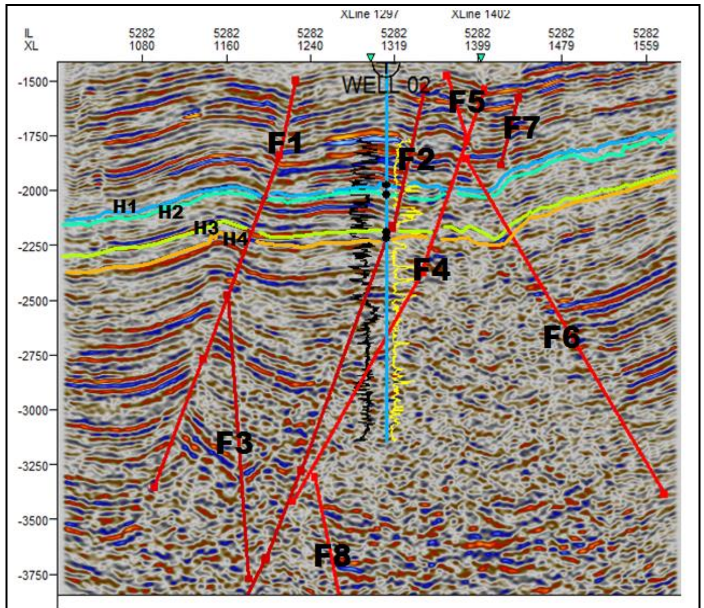

Figure 1: Well-to-seismic ties showing the mapped faults and horizons

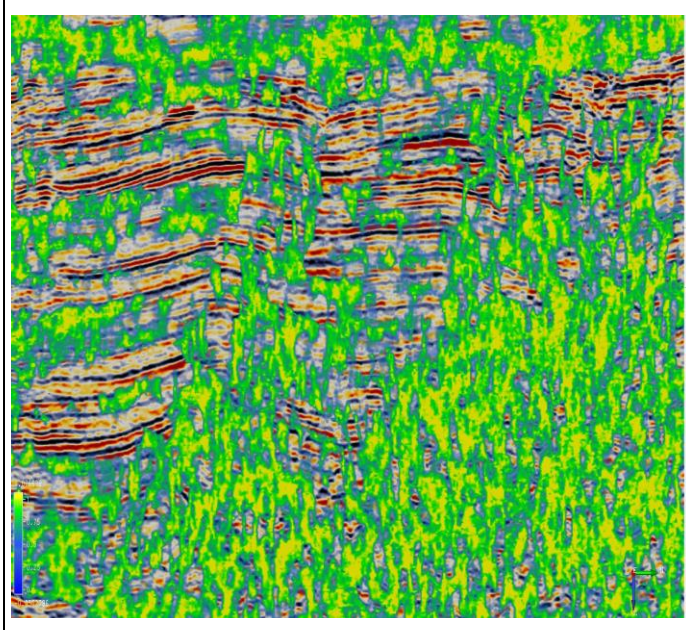

Figure 2: seismic chimneys analysis on inline 5282

CCB uses the concept of amplitude stacking of 3D seismic post stack data to enhance and detect subtle hydrocarbon–related seismic anomalies and to delineate gas-water, gas-oil and oil-water contacts which are essential parameters to estimate the oil-in-place. The conditions of these contacts affect well productivity as water production in relative to oil and gas production determines the life cycle of a well. Seismic coloured inversion allows rapid band-limited inversion of seismic traces transforming them into reflectivity traces through a designed operator in frequency domain. Traditional inversion techniques such as sparse-spike inversion are generally known to be time consuming, expensive and sophisticated that require expert users. Seismic colour inversion is however easy to use, cost effective, robust and model independent, where delineated reservoirs are shaper and better defined for qualitative interpretation and further seismic analysis.

Method

The 3D seismic reflection data used in this research comprises of 637 inlines and 595 crosslines with interval of 25, covering an area of 102 km^2. The number of the sampling intervals per trace is 1251 with sampling interval of 4msec. The quality of the seismic section was further improved by running the entire data over a dip steering attribute for optimal smoothening. Mapped and correlated reservoir sand units (R1 and R2) were tied to the wireline log using time to depth conversion technique to generate synthetic seismogram which was later employed for seismic colour inversion.

Seismic chimneys cube was constructed with other attributes such as similarity, curvature, energy and variance of dip (a measure of chaos) integrated into its formulation and later applied across the entire 3D seismic dataset. Ninety pickset seeds were selected for both "chimney YES" and "chimney NO", and thereafter a neural network management pattern recognition was applied with confidence level of 30 percent. This gives the chimney technology a chance to separate vertical disturbances, associated with seepage related features of high amplitude events, from localized disturbance across the entire seismic section. Common contour binning was applied on already structurally mapped polygons on both R1 and R2 horizons. CCB is based on two assumptions; firstly, the seismic traces that penetrate a hydrocarbon bearing reservoir at the same depth would have identical hydrocarbon columns. Also, all the stacking traces along contour lines enhance possible hydrocarbon effects while the stratigraphic variations and noise are cancelled. The implication of the second assumption is that when all stacked traces are along the same contour lines, then hydrocarbon effects are expected to be constructively stacked, while both stratigraphic variations and random noise would cancel out.

The designated polygon on R1 has inline/crossline (5101/1031 - 5585/1557) of 1251 samples with Z-values (450 - 700 msec.). However, the mapped structurally polygon for R2 of 5126/1048 to 5582/ 1562 has 1251 samples and Z-slice values (500 - 750 msec.); a total of 260483 were stacked for CCB of R2 horizon.

Seismic coloured inversion takes an approach similar to seismic processing. The 3D seismic dataset and well 001 sonic and density logs spectra were analyzed to define an operator that could shape the average seismic trace spectra to that of a fitted curve representative of the average acoustics impedance spectrum. This defines the amplitude spectrum of the required operator. The phase spectrum is rotated by -90 degrees; a bandpass filter is applied and the new spectrum is converted to time. The designed SCI operator in time domain is applied to the entire seismic volume using convolution algorithm. In this research, the low cut and high cut of the designed operator at -60 dB amplitude were 3 Hz and 108 Hz respectively.

Results and Discussion

During the seismic interpretation, three major faults (F1, F2, and F4) were delineated along with other intermediate faults (F3 and F6) and minor faults (F7 and F8) (Figure 1). The entire structural trapping mechanism consists of anticlinal structure at the center of OPO field tying to the crest of the rollover structure assisted by faults. This appears to be the principal structure responsible for hydrocarbon entrapment in this hydrocarbon field. OPO field is characteristically associated with large faults closure against a series of down-to-south growth faults (F1, F2, and F4). Intermediate faults (F3 and F6) interpreted to be antithetic and synthetic faults dissected the main body of the field. Structural highs inform of diapiric structures which perhaps constitute structural traps for hydrocarbon are localized on the field.

Chimney processing uses multi-directional attributes combined via a neural network to highlight chimneys in the dataset. Expected chimneys are picked in the data, and used to train the neural network to find similar features. The entire processes result in the creation of chimney cube. Fig. 2 shows the seismic chimneys observed on inline 5282. Chimneys are found throughout the entire 3D seismic dataset pointing to the localization of faults and fluid migration paths. The fluid migration appears to be vertically upward with larger portion of these fluids settling closer to the surface about 1.5 and 1.7 seconds (Figure 2). This may be an indication that the delineated faults in this field are perhaps leaking, where the trapped hydrocarbon have seeped or migrated upwards as seepages.

The results of un-flattened CCB of seismic amplitude in both mapped reservoir sand units (R1 and R2) are shown in Figure 3(a and b). The signal amplitudes for both reservoirs range 0 - 15000 trending predominantly NE-SW. Two gas-oil contacts (GOC) at 620 and 680 Z-slices were mapped out from CCB stacked of R1 while one GOC at 540 Z-slice values with two oil-water contacts (OWC) at both 570 and 630 Z-slices values respectively were delineated from CCB stacked of R2. Pockets of gas are predominant in reservoir R1 with less oil (shown as red), whereas reservoir R2 is rich in oil towards the SW and NW areas (Figure 3 c and d). The observed oil water contacts in R2 (Figure 3b) are fairly sharp covering a few feet. The top of the transition zone which is the contact between the oil and water is known to be the base of the clean oil production, while the base of the transition zone is the top of free water zone. The length of this transition zone in Fig. 3b is observed to be relatively short denoting higher permeability of reservoir R2.

SciQt window in Fig. 4 displays the residual operator (QC) chart. This chart displays the band-limited well log impedance curve fit (green). Also displayed is the smooth mean spectrum (red) of the Colour Inverted alternative set (QC) of random traces. As it can be noticed, this spectrum overlays the band well log impedance curve fit within the band width. The residual operator (blue) should have essentially zero amplitude within the band width. Following this chart is a similar Design Operator chart, which displays the band limited well log impedance curve fit (green), the smooth seismic mean spectrum (red) and the derived Coloured Inversion operator spectrum (blue). The Coloured Inversion operator shapes the smooth seismic mean spectrum to the band limited well log impedance curve fit at every frequency. Log Input chart displays the well impedance logs in time domain. In this case, there is only one impedance log, but typically there are more. Also displayed on this chart is the trend line (black). Reflectors in seismic inverted section on inline 5364 as shown Figure 4 are sharper with improved definition. The intervals of the mapped reservoir units in the inverted seismic section also appear better defined for qualitative interpretation.

Conclusions

The following are the conclusions drawn from this study:

1. Seismically derived chimneys showed upward migration of hydrocarbon pool in the study area localized closer to the surface. The mapped faults seem to have lost their integrity; it appears the faults are non-sealing as evident from the chimney analysis. It is recommended that proposed wells in this field should be within 600-1000 msec.
2. Common contour binning (CCB) attributes revealed that the reservoir sand unit R1 in F-Field is more of gas filled, whereas R2 is oil filled. Both GOC and OWC contacts were delineated and mapped across the reservoir sand units.
3. Applying seismic coloured inversion on the seismic volume in this field revealed the reflectors and reservoir units sharper and clearer for further analysis and qualitative interpretations. Subtle features were better defined on the seismic sections for mapping.

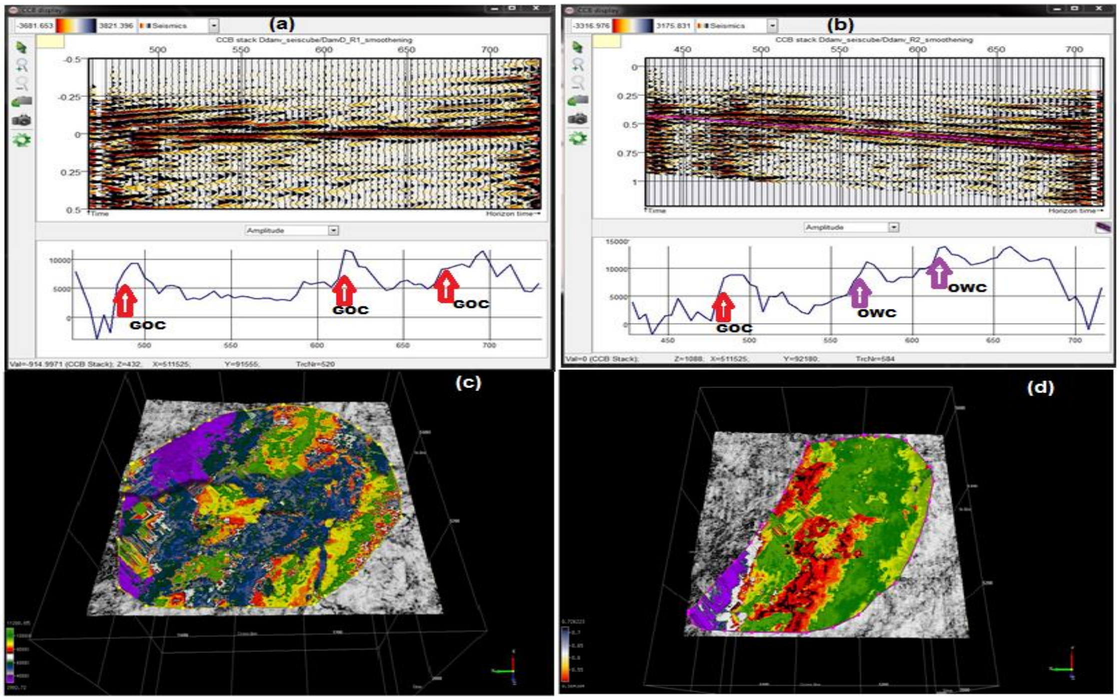

Figure 3: Common contour binning (CCB) attributes analysis on reservoir R1 (a, c) and R2 (b, d)

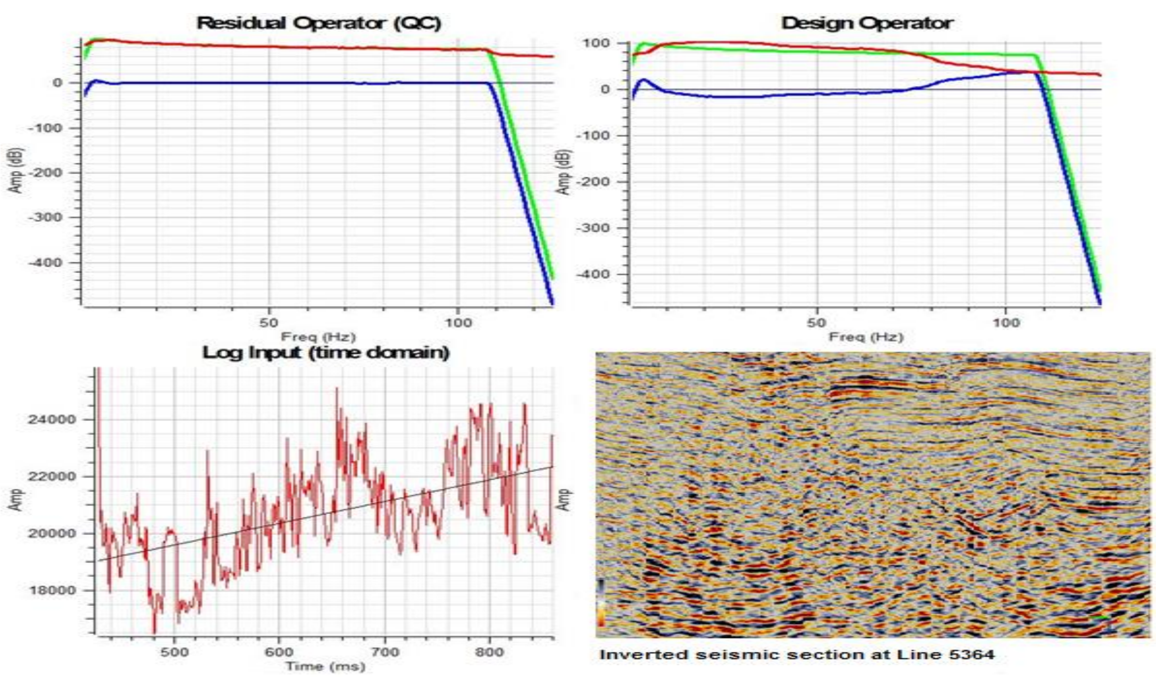

Figure 4: Seismic inversion parameters and the inverted section on inline 5364

EDITED REFERENCES

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